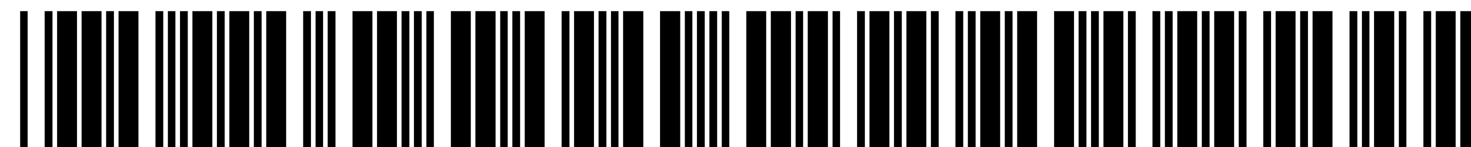

US009608161B2

(12) **United States Patent**
Wang et al.

(10) **Patent No.: US 9,608,161 B2**
(45) **Date of Patent: Mar. 28, 2017**

(54) **SEMICONDUCTOR LIGHT-EMITTING DEVICE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/941,683**

(22) Filed: **Nov. 16, 2015**

(65) **Prior Publication Data**

US 2016/0181472 A1 Jun. 23, 2016

(30) **Foreign Application Priority Data**

Dec. 23, 2014 (TW) .... 103144979 A

(51) **Int. Cl.**
H01L 33/32 (2010.01)
H01L 33/14 (2010.01)
H01L 33/02 (2010.01)
H01L 33/04 (2010.01)

(52) **U.S. Cl.**
CPC ***H01L 33/14*** (2013.01); ***H01L 33/02*** (2013.01); *H01L 33/04* (2013.01); *H01L 33/32* (2013.01)

(58) **Field of Classification Search**
CPC H01L 33/14; H01L 33/32; H01L 33/42; H01L 33/06; H01L 33/325; H01L 33/38; H01L 33/0025; H01L 33/0075; H01L 33/12; H01L 33/20; H01L 33/02; H01L 33/04
See application file for complete search history.

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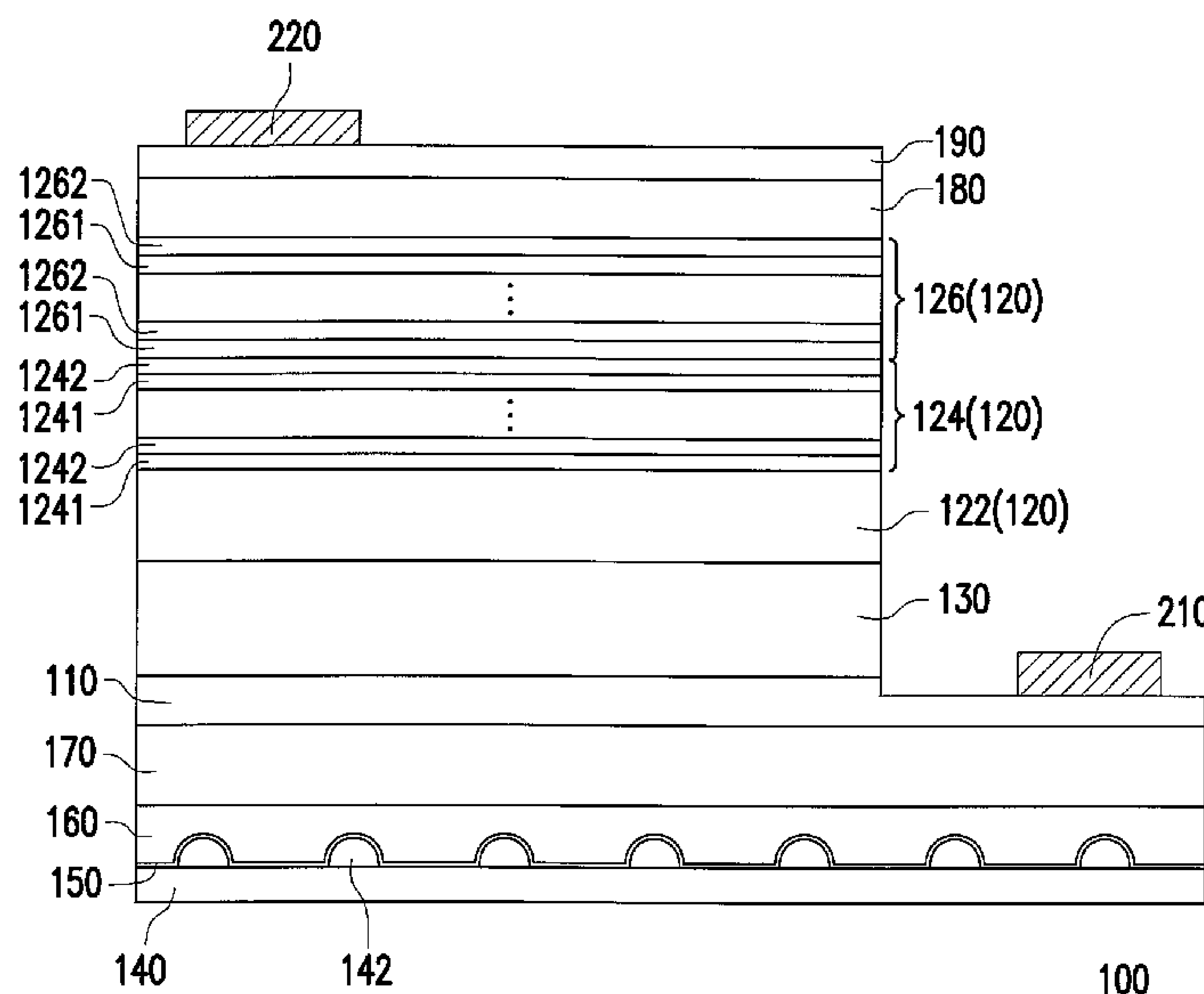
(57) **ABSTRACT**

A semiconductor light-emitting device including an N-type semiconductor layer, a plurality of P-type semiconductor layers, a light-emitting layer, and a contact layer is provided. The light-emitting layer is disposed between the N-type semiconductor layer and the whole of the P-type semiconductor layers. The P-type semiconductor layers are disposed between the contact layer and the light-emitting layer. All the P-type semiconductor layers between the light-emitting layer and the contact layer include aluminum.

6 Claims, 2 Drawing Sheets



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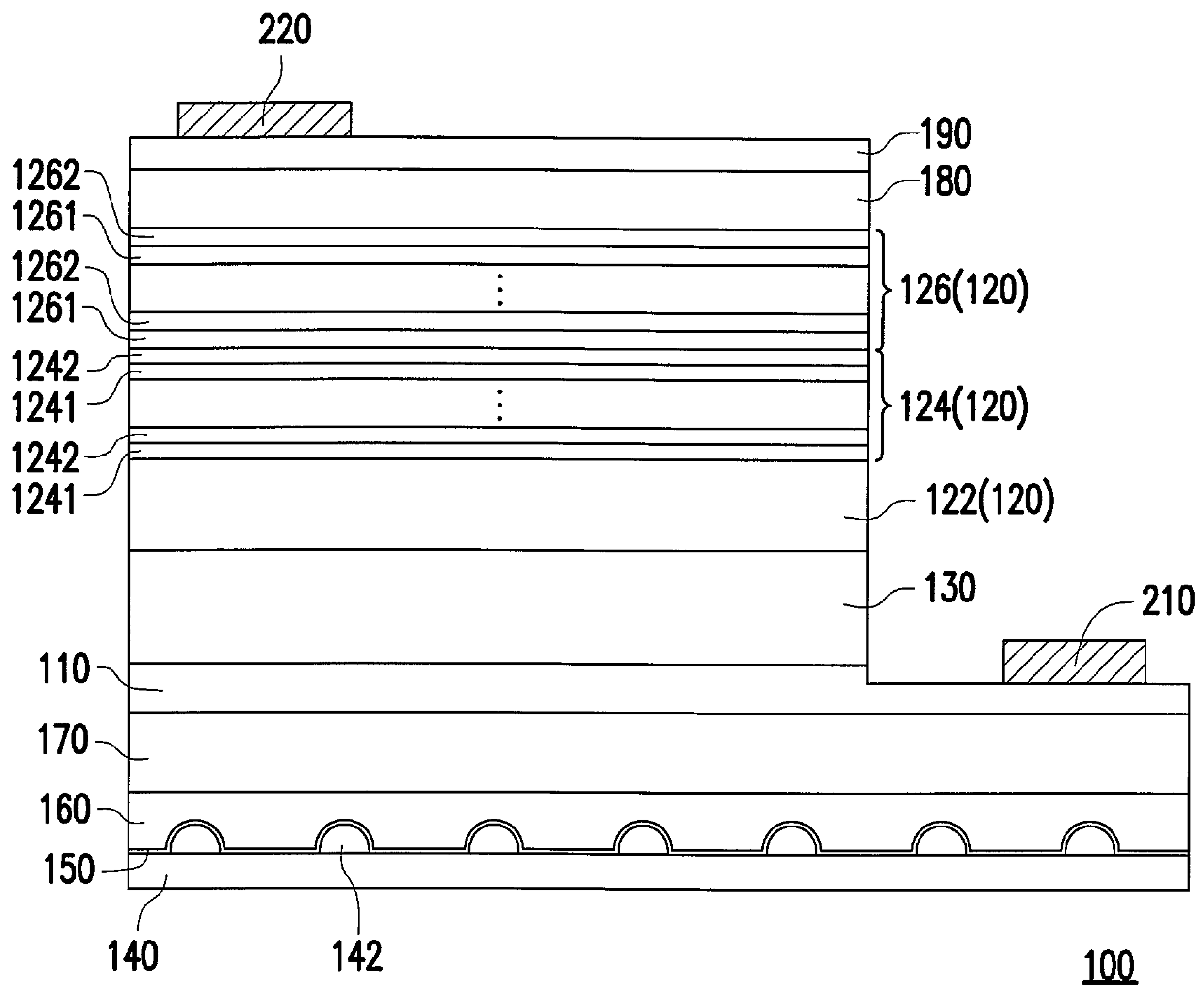

FIG. 1

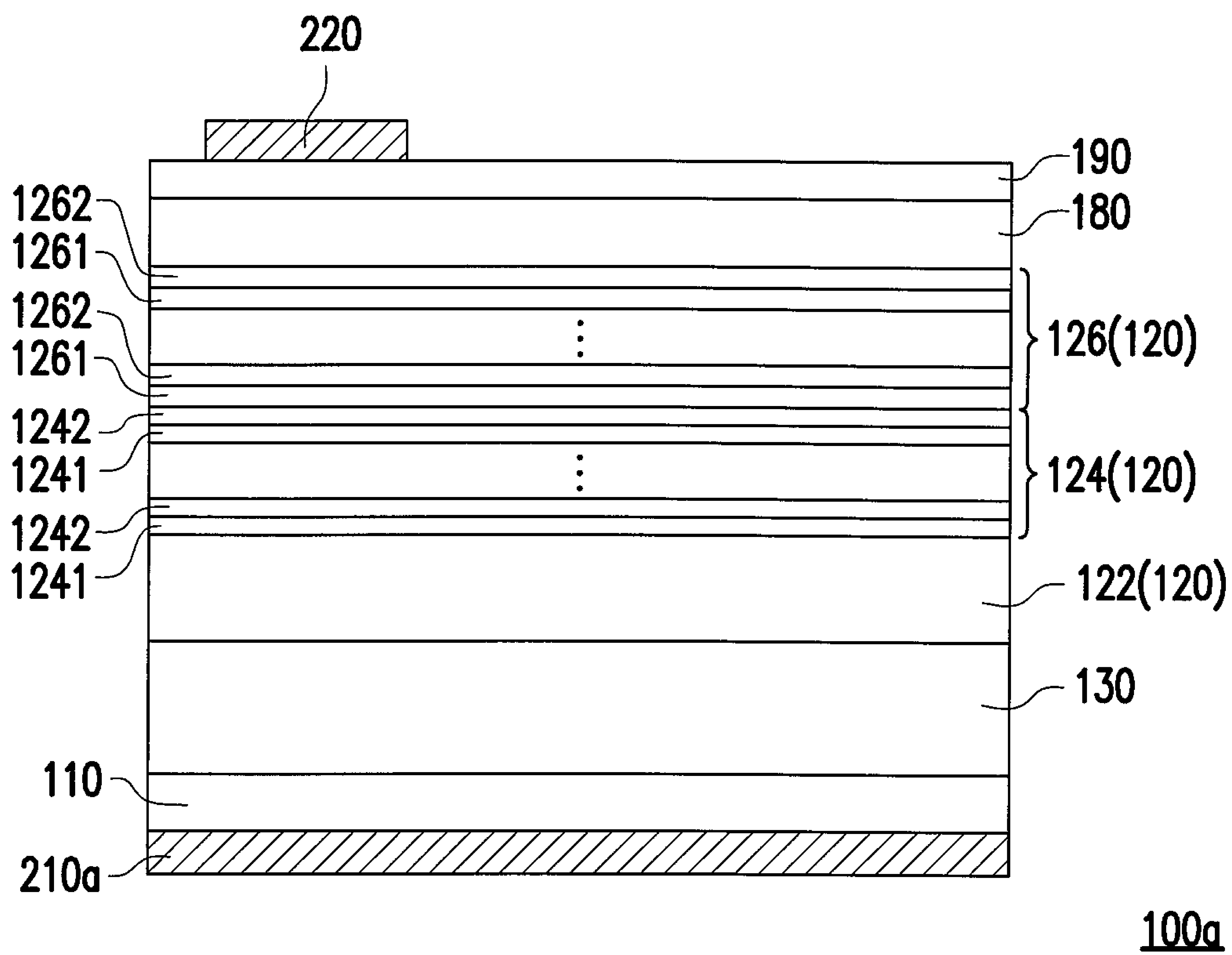

FIG. 2

SEMICONDUCTOR LIGHT-EMITTING DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the priority benefit of Taiwan application serial no. 103144979, filed on Dec. 23, 2014. The entirety of the above-mentioned patent application is hereby incorporated by reference herein and made a part of this specification.

BACKGROUND

Field of the Invention

The invention is directed to a light-emitting device and more particularly, to a semiconductor light-emitting device.

Description of Related Art

With the evolution of photoelectrical technology, traditional incandescent bulbs and fluorescent lamps have been gradually replaced by solid-state light sources of the new generation, such as light-emitting diodes (LEDs). The LEDs have advantages, such as long lifespans, small sizes, high shock resistance, high light efficiency and low power consumption and thus, have been widely adopted as light sources in applications including household lighting appliances as well as various types of equipment. Besides being widely adopted in light sources of backlight modules of liquid crystal displays (LCDs) and household lighting appliances, the application of the LEDs have been expanded to street lighting, large outdoor billboards, traffic lights and the related fields in recent years. As a result, the LEDs have been developed as the light sources featuring economic power consumption and environmental protection.

Recently, most developers of solid-state light sources make effort to pursue good luminance efficiency. Subjects with respect to improving the luminance efficiency of the LEDs are generally divided into how to improve internal quantum efficiency (i.e., luminance efficiency of a light-emitting layer) and how to improve external quantum efficiency (which is further affected by light extraction efficiency). However, in a conventional gallium nitride (GaN) LED, a band gap between a P-type GaN semiconductor layer and an N-type GaN semiconductor layer is approximate to a band gap of the light-emitting layer, such that blue light or ultraviolet (UV) light emitted from the light-emitting layer is easily absorbed, which leads to reduced luminance efficiency of the LED.

SUMMARY

The invention provides a semiconductor light-emitting device with better luminescence efficiency.

According to an embodiment of the invention, a semiconductor light-emitting device including an N-type semiconductor layer, a plurality of P-type semiconductor layers, a light-emitting layer and a contact layer. The light-emitting layer is between the N-type semiconductor layer and the whole of the P-type semiconductor layers. The P-type semiconductor layers are disposed between the contact layer and the light-emitting layer. All the P-type semiconductor layers between the light-emitting layer and the contact layer include aluminum.

In an embodiment of the invention, the P-type dopant of the P-type semiconductor layers is a group IIA element dopant.

In an embodiment of the invention, the group IIA element dopant is a magnesium (Mg) dopant.

In an embodiment of the invention, the P-type semiconductor layers include a first P-type super lattice layer and a P-type indium aluminum gallium nitride (InAlGaN) layer. The P-type InAlGaN layer is disposed between the light-emitting layer and the first P-type super lattice layer, and the first P-type super lattice layer is disposed between the P-type InAlGaN layer and the contact layer.

In an embodiment of the invention, the first P-type super lattice layer includes a plurality of first P-type aluminum gallium nitride (AlGaN) layers and a plurality of second P-type AlGaN layers which are alternately stacked, and the concentration of the P-type dopant in each of the first P-type AlGaN layers is different from the concentration of the P-type dopant in each of the second P-type AlGaN layers.

In an embodiment of the invention, the P-type semiconductor layers further include a second P-type super lattice layer disposed between the first P-type super lattice layer and the contact layer, and the concentration of aluminum in the second P-type super lattice layer is lower than the concentration of aluminum in the first P-type super lattice layer.

In an embodiment of the invention, the second P-type super lattice layer includes a plurality of third P-type AlGaN layers and a plurality of fourth P-type AlGaN layers which are alternately stacked, and the concentration of the P-type dopant in each of the third P-type AlGaN layers is different from the concentration of the P-type dopant in each of the fourth P-type AlGaN layers.

In an embodiment of the invention, the contact layer is an ohmic contact layer.

In an embodiment of the invention, the semiconductor light-emitting device further includes a first electrode and a second electrode. The first electrode is electrically connected to the N-type semiconductor layer, and the second electrode is disposed on the contact layer.

In an embodiment of the invention, light emitted from the light-emitting layer comprises blue light, ultraviolet (UV) light or a combination thereof.

In the semiconductor light-emitting device provided by the embodiments of the invention, since all the P-type semiconductor layers between the light-emitting layer and the contact layer contain aluminum, a band gap of each of the P-type semiconductor layers can be increased. In this way, the light emitted from the light-emitting layer can be less absorbed by the P-type semiconductor layers, such that the luminance efficiency of the semiconductor light-emitting device can be enhanced.

In order to make the aforementioned and other features and advantages of the invention more comprehensible, several embodiments accompanied with figures are described in detail below.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings are included to provide a further understanding of the invention, and are incorporated in and constitute a part of this specification. The drawings illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

FIG. **1** is a cross-sectional diagram illustrating a semiconductor light-emitting device according to an embodiment of the invention.

FIG. **2** is a cross-sectional diagram illustrating a semiconductor light-emitting device according to another embodiment of the invention.

DESCRIPTION OF EMBODIMENTS

FIG. **1** is a cross-sectional diagram illustrating a semiconductor light-emitting device according to an embodiment of the invention. With reference to FIG. **1**, a semiconductor light-emitting device **100** of the present embodiment includes an N-type semiconductor layer **110**, a plurality of P-type semiconductor layers **120**, a light-emitting layer **130** and a contact layer **180**. The light-emitting layer **130** is disposed between the N-type semiconductor layer **110** and the whole of the P-type semiconductor layers **120**. The P-type semiconductor layers **120** are disposed between the contact layer **180** and the light-emitting layer **130**. Light emitted from the light-emitting layer **130** may include blue light, ultraviolet (UV) light or a combination thereof. In the present embodiment, the light-emitting layer **130** may be, for example, a multiple quantum well (MQW) layer formed by alternately stacking a plurality of N-type indium gallium nitride (InGaN) layers and a plurality of N-type gallium nitride (GaN) layers, which is capable of emitting the blue light. Additionally, in the present embodiment, all the P-type semiconductor layers **120** between the light-emitting layer **130** and the contact layer **180** contain aluminum.

In the semiconductor light-emitting device **100** of the present embodiment, since all the P-type semiconductor layers **120** between the light-emitting layer **130** and the contact layer **180** contain aluminum, the band gap of each P-type semiconductor layer **120** can be enhanced. In this way, the light (e.g. the blue light, the UV light or the combination thereof) emitted from the light-emitting layer **130** may be less absorbed by the P-type semiconductor layers **120**, such that luminance efficiency of the semiconductor light-emitting device **100** can be improved.

In the present embodiment, the P-type dopant of the P-type semiconductor layers **120** is a group IIA element dopant, such as an Mg dopant. Additionally, in the present embodiment, the P-type semiconductor layers **120** includes a first P-type super lattice layer **124** and a P-type indium aluminum gallium nitride (InAlGaN) layer **122**. The P-type InAlGaN layer **122** is disposed between the light-emitting layer **130** and the first P-type super lattice layer **124**, and the first P-type super lattice layer **124** is disposed between the P-type InAlGaN layer **122** and the contact layer **180**.

In the present embodiment, the first P-type super lattice layer **124** includes a plurality of first P-type aluminum gallium nitride (AlGaN) layers **1241** and a plurality of second P-type AlGaN layers **1242** which are alternately stacked, where the concentration of the P-type dopant (e.g., the doping concentration of Mg) in each first P-type AlGaN layer **1241** is different from the concentration of the P-type dopant (e.g., the doping concentration of Mg) in each second P-type AlGaN layer **1242**.

In the present embodiment, the P-type semiconductor layers **120** further include a second P-type super lattice layer **126** disposed between the first P-type super lattice layer **124** and the contact layer **180**, in which the concentration of aluminum in the second P-type super lattice layer **126** is lower than the concentration of aluminum in the first P-type super lattice layer **124**. In the present embodiment, the second P-type super lattice layer **126** includes a plurality of third P-type AlGaN layers **1261** and a plurality of fourth P-type AlGaN layers **1262** which are alternately stacked, in which the concentration of the P-type dopant (e.g., the doping concentration of Mg) in each third P-type AlGaN layer **1261** is different from the concentration of the P-type dopant (e.g., the doping concentration of Mg) in each fourth P-type AlGaN layer **1262**.

In an embodiment, the doping concentration of Mg in each first P-type AlGaN layer **1241** may fall within a range from 10^{19} atoms/cm^3 to 10^{20} atoms/cm^3, and a mole ratio of aluminum therein may fall within a range of 10~15%. The doping concentration of Mg of in each second P-type AlGaN layer **1242** may fall within a range from 5×10^{18} atoms/cm^3 to 5×10^{19} atoms/cm^3, and a mole ratio of aluminum therein may fall within a range of 1~5%. The doping concentration of Mg in each third P-type AlGaN layer **1261** may fall within a range from 10^{19} atoms/cm^3 to 5×10^{19} atoms/cm^3, and a mole ratio of aluminum therein may fall within a range of 3~8%. The doping concentration of Mg of in each fourth P-type AlGaN layer **1262** may fall within a range from 5×10^{18} atoms/cm^3 to 10^{19} atoms/cm^3, and a mole ratio of aluminum therein may fall within a range of 1~3%.

In other embodiments, the semiconductor light-emitting device **100** may include the first P-type super lattice layer **124**, but no second P-type super lattice layer **126**.

In the present embodiment, the N-type semiconductor layer **110** is, for example, an N-type gallium nitride (GaN) layer. Additionally, in the present embodiment, the semiconductor light-emitting device **100** further includes a first electrode **210** and a second electrode **220**. The first electrode **210** is electrically connected to the N-type semiconductor layer **110**, e.g., disposed on the N-type semiconductor layer **110**, and the second electrode **220** is disposed on the contact layer **180**. In the present embodiment, the semiconductor light-emitting device **100** further includes a transparent conductive layer **190** (e.g., an indium tin oxide (ITO) layer) disposed on the contact layer **180**, and the second electrode **220** is disposed on the transparent conductive layer **190**. The contact layer **180** serves to reduce contact resistance between the transparent conductive layer **190** and the P-type semiconductor layers **120**. In the present embodiment, the contact layer **180** is an ohmic contact layer, which is a conductor, i.e., a P-type doped layer with a high concentration P-type dopant or an N-type doped layer with a high concentration N-type dopant. In an embodiment, the concentration of an electron donor or an electron acceptor in the contact layer **180** is greater than or equal to 10^{20} atoms/cm^3, and thus, the conductivity of the contact layer **180** is similar to the conductivity of a conductor. For example, the contact layer **180** may be a P-type InGaN layer, e.g., an Mg-doped InGaN layer.

In the present embodiment, the semiconductor light-emitting device **100** may further include a substrate **140**, a nucleation layer **150**, a buffer layer **160** and an unintentionally doped semiconductor layer **170**. In the present embodiment, the substrate **140** is a patterned sapphire substrate having surface patterns **142** (e.g., protruding patterns) to provide a light-scattering effect, so as to improve light extraction efficiency. The nucleation layer **150**, buffer layer **160**, the unintentionally doped semiconductor layer **170**, the N-type semiconductor layer **110**, the light-emitting layer **130**, the P-type semiconductor layers **120**, contact layer **180**, the transparent conductive layer **190** and the second electrode **220** are stacked in sequence on the substrate **140**. In the present embodiment, the nucleation layer **150**, the buffer layer **160** and the unintentionally doped semiconductor layer **170** are made of, for example, unintentionally doped GaN.

FIG. **2** is a cross-sectional diagram illustrating a semiconductor light-emitting device according to another embodiment of the invention. With reference to FIG. **2**, a

semiconductor light-emitting device **100***a* of the present embodiment is similar to the semiconductor light-emitting device **100** of the embodiment illustrated in FIG. **1**, but different therefrom in below. The semiconductor light-emitting device **100** of FIG. **1** is a horizontal-type light-emitting diode (LED), in which both the first electrode **210** and the second electrode **220** are located at the same side of the semiconductor light-emitting device **100**, while the semiconductor light-emitting device **100***a* of the present embodiment is a vertical-type LED, in which a first electrode **210***a* and the second electrode **220** are located at opposite sides of the semiconductor light-emitting device **100**. In the present embodiment, the first electrode **210***a* is an electrode layer disposed on a surface of the N-type semiconductor layer **110** which faces away from the light-emitting layer **130**. However, in other embodiments, a conductive substrate may be disposed between the first electrode **210***a* and the N-type semiconductor layer **110**. Namely, the first electrode **210***a* and the N-type semiconductor layer **110** may be respectively disposed on opposite surfaces of the conductive substrate.

To summarize, in the semiconductor light-emitting device provided by the embodiments of the invention, since all the P-type semiconductor layers between the light-emitting layer and the contact layer contain aluminum, the band gap of each of the P-type semiconductor layers can be increased. In this way, the light emitted from the light-emitting layer be less absorbed by the P-type semiconductor layers, such that the luminance efficiency of the semiconductor light-emitting device can be improved.

Although the invention has been described with reference to the above embodiments, it will be apparent to one of the ordinary skill in the art that modifications to the described embodiment may be made without departing from the spirit of the invention. Accordingly, the scope of the invention will be defined by the attached claims not by the above detailed descriptions.

What is claimed is:

1. A semiconductor light-emitting device, comprising:
- an N-type semiconductor layer;
- a plurality of P-type semiconductor layers;
- a light-emitting layer, disposed between the N-type semiconductor layer and the whole of the P-type semiconductor layers; and
- an indium gallium nitride (InGaN) contact layer, wherein the P-type semiconductor layers are disposed between the InGaN contact layer and the light-emitting layer,
- wherein all the P-type semiconductor layers between the light-emitting layer and the InGaN contact layer comprise aluminum, and the P-type semiconductor layers further comprise:
  - a first P-type super lattice layer; and
  - a P-type indium aluminum gallium nitride (InAlGaN) layer, disposed between the light-emitting layer and the first P-type super lattice layer, wherein the first P-type super lattice layer is disposed between the P-type InAlGaN layer and the InGaN contact layer,
- wherein the first P-type super lattice layer comprises a plurality of first P-type aluminum gallium nitride (AlGaN) layers and a plurality of second P-type AlGaN layers which are alternately stacked, and concentration of a P-type dopant in each of the first P-type AlGaN layers is different from concentration of a P-type dopant in each of the second P-type AlGaN layers,
- wherein the concentration of the P-type dopant in each of the first P-type AlGaN layers falls within a range from 10^{19} atoms/cm^3 to 10^{20} atoms/cm^3 and a mole ratio of aluminum therein falls within a range of 10~15%, and the concentration of the P-type dopant in each of the second P-type AlGaN layers falls within a range from 5×10^{18} atoms/cm^3 to 5×10^{19} atoms/cm^3 and a mole ratio of aluminum therein falls within a range of 1~5%,
- wherein the P-type semiconductor layers further comprise a second P-type super lattice layer disposed between the first P-type super lattice layer and the InGaN contact layer, and concentration of aluminum in the second P-type super lattice layer is lower than concentration of aluminum in the first P-type super lattice layer,
- wherein the second P-type super lattice layer comprises a plurality of third P-type AlGaN layers and a plurality of fourth P-type AlGaN layers which are alternately stacked, and concentration of a P-type dopant in each of the third P-type AlGaN layers is different from concentration of a P-type dopant in each of the fourth P-type AlGaN layers,
- wherein the concentration of the P-type dopant in each of the third P-type AlGaN layers falls within a range from 10^{19} atoms/cm^3 to 5×10^{19} atoms/cm^3 and a mole ratio of aluminum therein falls within a range of 3~8%, and the concentration of the P-type dopant in each of the fourth P-type AlGaN layers falls within a range from 5×10^{18} atoms/cm^3 to 10^{19} atoms/cm^3 and a mole ratio of aluminum therein falls within a range of 1~3%, and
- wherein a doping concentration in the contact layer is greater than a doping concentration in each of the plurality of p-type semiconductors layers.

2. The semiconductor light-emitting device according to claim **1**, wherein the P-type dopant of the P-type semiconductor layers is a group IIA element dopant.

3. The semiconductor light-emitting device according to claim **2**, wherein the group IIA element dopant is a magnesium (Mg) dopant.

4. The semiconductor light-emitting device according to claim **1**, wherein the InGaN contact layer is an ohmic contact layer.

5. The semiconductor light-emitting device according to claim **1**, further comprising:
- a first electrode, electrically connected to the N-type semiconductor layer; and
- a second electrode, disposed on the InGaN contact layer.

6. The semiconductor light-emitting device according to claim **1**, wherein light emitted from the light-emitting layer comprises blue light, ultraviolet (UV) light or a combination thereof.

* * * * *